# eRD103: High-Performance DIRC (hpDIRC)

**August 31, 2021**

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The objective of the R&D program proposed below is to optimize, validate, and finalize the design of the high-performance DIRC (hpDIRC) detector. All currently proposed EIC central detector designs consider the hpDIRC as a leading option for barrel PID. The previous generic R&D program (initially eRD4, later eRD14 EIC PID consortium) demonstrated the feasibility of the hpDIRC to provide $3\sigma$ or more separation of $\pi/K$ up to 6 GeV/$c$, $e/K$ up to 6 GeV/$c$, $e/\pi$ up to at least 1.2 GeV/$c$, and $K/p$ up to 10 GeV/$c$. The ultimate goal of the remaining program is to demonstrate the hpDIRC performance in a test beam with a prototype that is representative of the intended EIC hpDIRC configuration. The proposed activities for FY22 will focus on the hpDIRC aspects and components common to all three proposals (small-pixel photosensors, high-precision timing, advanced optics, *etc.*).

## 1 R&D plan for FY22

**hpDIRC Prototype Development**

The development and validation of radiation-hard 3-layer lens prototypes was a key achievement of the generic hpDIRC R&D program. Now the hardware focus shifts towards the incremental development of the full-system hpDIRC prototype. The initial setup will be based on the PANDA Barrel DIRC optics and readout as well as several Photonis XP85012 MCP-PMTs with a pixel pitch of 6.5mm. Once the prototype components from GSI arrive in the U.S. they will be tested in the SBU DIRC lab and reassembled. Tests will include the validation of the sensors, readout electronics, and DAQ system with a picosecond laser pulser as light source.

A lot of effort will have to go towards developing **a working combination of small pixel sensors and a fast readout system to match the required timing precision**. The only commercially available MCP-PMT candidates with pixels sizes of 3.5 mm or less are the PHOTONIS XP85122-S (with a pixel pitch of 1.6 mm, to be grouped into 3.2 mm pixels) and the Photek MAPMT 253 (with a pixel pitch of 3.5 mm). One of each sensors was purchased as part of generic R&D and the UH and Nalu group plan to combine them with the ASIC readout electronics they developed. Fabrication costs are engineering estimates, based upon similar development efforts at the University of Hawaii Instrumentation Development Laboratory. The budget lists the request for provided equipment and engineering support from Nalu Scientific. The complete readout units will be finally tested with a picosecond laser pulser and cosmic rays in the SBU DIRC lab.

**A new Cosmic Ray Telescope (CRT) setup** is being planned at SBU that would be used for initial tests and performance study of the DIRC prototype as well as the evaluation of the commercial small-pixel MCP-PMTs and Hawaii electronics with Cherenkov photons. The first milestone will be to reproduce the PANDA Barrel DIRC results from the CERN beam tests in a reference measurement, using the PANDA optics and XP85012 MCP-PMTs (with 6.5mm pixel pitch). SBU group will take lead on setting up the CRT setup with contributions from CUA, GSI, and ODU groups. Funds requested by SBU will be used for the acquisition of a 2k-channel readout system based on the VMM3 chip and SRS, the hardware of the assembly structure, and gas supply necessary for the CRT tracker system.

The mid-term goal is to assemble an **EIC DIRC prototype with small pixel-size sensors and readout electronics**, capable of validating the simulated performance and to directly measure the PID performance with a mixed hadron beam in the summer 2023. If the 32x32 channel version of the 10cmx10cm Gen III HRPPD becomes available in time, the next step would be to instrument one half of the prototype readout plane with HRPPDs and the other half with commercial MCP-PMTs to directly compare the sensor performance. All sensors envisioned for the FY23 prototype, preferable both the commercial MCP-PMTs and the HRPPDs, would have to be in hand several months before a scheduled beam test to evaluate the sensors in the lab and to validate the performance in combination with the readout electronics prior to the 2023 beam test. **This means that procurement of a sufficient number of sensors has to be initiated the summer of 2022**.

If the DIRC bars from the BaBar experiment can be extracted from the bar boxes without compromising the high optical and mechanical quality, use of these bars for the EIC hpDIRC could reduce the hpDIRC cost by 30-50%, depending on the details of the design.**Measurements of the mechanical and optical quality of the surfaces are of critical importance to decide if the disassembly results in bars of a sufficiently high quality.** An optical DIRC lab at JLab or one of the US DIRC institutions will be needed to evaluate significant part of bars after disassembly. Creating such a setup in time for the QA of the disassembly procedure would be very beneficial to the BaBar DIRC bar reuse project. Potential coverage of the cost of the disassembly and QA project is being discussed with JLab management.

**Software Plans**

Dr Wickramaarachchi will be responsible for the prototype simulation and reconstruction as well as the commissioning of the prototype readout electronics and DAQ. He will also study the beam instrumentation requirements for the FermiLab beamline in simulation. In the future he is expected to lead the analysis of the prototype data. The experience from the prototype simulation will be applied to improve the current hpDIRC design.

Following the initial hpDIRC design implementation, it is now important to study in detail the effect of different focusing system options, expansion volume shapes and dimensions, and the MCP-PMT arrangement, on the DIRC performance to identify a credible and cost-efficient baseline design for the hpDIRC that will be validated in the final hpDIRC prototype test in FY24.

**Summary of Proposed Activities**

**Software:**

- Compare the performance of different hpDIRC geometries (radiator bar size, focusing, prism shape, MCP-PMT arrangement, bar-plate hybrid optics).
- Study the hpDIRC performance with different magnetic field options and background in the full EIC detector implementation.
- Software: Complete the prototype simulation, evaluate the expected performance with cosmic rays and particle beams, and determine the requirements for supplemental beamline instrumentation.

**Hardware:**

- Hardware: Set up the PANDA-based prototype DAQ system and commission the PHOTONIS XP85012 MCP-PMTs with TRB/PADIWA-based readout electronics.
- Assemble PANDA-like DIRC prototype for the cosmic ray tests.
- Prepare small-pixel MCP-PMTs and Hawaii readout and integrate them into the hpDIRC prototype.
- Purchase sensors for 2023 hpDIRC Prototype (commercial MCP-PMTs and HRPPDs).
- Study the optical and mechanical quality of the DIRC radiator bar after the BaBar DIRC barbox disassembly.
- Incrementally upgrade the prototype based on available components (sensors, readout electronics).

## 2 Manpower required and available for FY22

Dr. Nilanga Wickramaarachchi was hired as a Postdoctoral researcher at CUA with 50% support from the generic R&D program. Maintaining the support of his position will be crucial for success of the proposed hpDIRC R&D program.

Funding is requested for Postdoctoral fellow Tripathi to work on the design and fabrication of an interface board to mate the photosensors to the Nalu Scientific-provided readout ASICs and backend connection cards.

Postdoctoral researcher at ODU would be responsible for developing lab for disassembled bars QA and performing bar scans.

In-kind manpower: Dr. Roman Dzhygadlo (GSI), Dr. Charles Hyde (ODU), Dr. Greg Kalicy (CUA), Dr. Albert Lehmann, (Erlangen University), Dr. Maria Patsyuk (JINR), Dr. Carsten Schwartz (GSI), Dr. Jochen Schwiening (GSI), Dr. Gary Varner (UH)

# 3 Milestones for FY22

- Validation of prototype DAQ for PHOTONIS XP85012 MCP-PMT array with TRB/PADIWA-based readout electronics and initial PANDA-like DIRC Prototype tested in CRT.
- Working readout for small pixel MCP-PMT leading candidates.
- Performance comparison of various EIC DIRC design options.
- Cost/performance optimized hpDIRC design.

# 4 FY22 Funding request

| **Item** | **Institution** | **Requested** |
|---|---|---|
| Postdoc,50% | CUA | \$80k |
| QA of BaBar DIRC bars | CUA | \$50k |
| Prototype Evaluation at CRT | CUA | \$20k |
| Prototype Equipment | CUA | \$10k |
| Sensors for 2023 EIC hpDIRC Prototype (CUA) | CUA | \$140k |
| Travel | CUA/GSI | \$10k |
| Postdoc, 50% | ODU | \$80k |
| CRT readout electronics | SBU | \$20k |
| CRT materials | SBU | \$15k |
| Postdoc, 50% | UH | \$60k |
| Test-bench/readout board assembly | UH | \$15k |
| ASIC and engineering support | Nalu | \$25k |
| **Total** | | \$525k |

**Budget Per Institution:**

| **Institution** | CUA | ODU | SBU | UH | Nalu | **Total** |
|---|---|---|---|---|---|---|
| **Requested** | \$310k | \$80k | \$35k | \$75k | \$25k | \$525k |

# 5 Preview of remaining R&D for FY23 and FY24

The remaining future R&D will focus mainly on the further development and study of the hpDIRC full system prototype. In FY23 we plan to focus on readout tests with a narrow bar, lens, prism prototype equipped with commercial and HRPPD MCP-PMTs. In FY24 the final hpDIRC prototype will study potential focusing arrangements and performance of the hybrid design with narrow bar and wide plate. This configuration has not been experimentally studied so far and could offer significant cost reduction. Transferred optics from the PANDA Barrel DIRC group will allow to test hybrid designs without investing in new optics (bar, plate, prism).

**FY23**

- Software preparation, assembly of EIC hpDIRC prototype and first studies with particle beams.
- Study of multiple tracks in same radiator/sector impact (jets, lower multiplicity, high multiplicity).
- Study of the possible imaging improvement from aspherical lens surfaces.

**FY24**

- Analysis of the previous testbeam data and software preparation for the final EIC hpDIRC prototype
- Assembly of the final EIC hpDIRC prototype and study with particle beams.